8

(*Reprinted from Journal Franklin Institute, June, 1906*)

Notes on Great Tunnels.*

By Lewis M. Haupt.

Prof. of Civil Engineering, Franklin Institute.

Mr. President and Members of the Institute:—

Tunnels, like bridges, are engineering devices for overcoming physical obstacles to traffic.

Although of ancient origin their recent great development is the outcome of the demands of modern civilization resulting from the increase in population and commerce.

The advent of railroads in 1827 gave an impetus to the building of tunnels to save time, distance and grade in the interchange of traffic. These "horizontal wells," as they were called, were excavated by hand labor, as they were comparatively short, but with the increase of tonnage and demands for greater economy in cost and time, more pretentious enter-

*Revised for publication.

prises were undertaken, requiring the use of machinery and power for their completion. Thus the ingenuity of man was impressed to meet the difficult requirements of providing an unobstructed passageway through mountains or under rivers or city streets, in the least time and at a moderate cost.

It was not until tunneling machinery was reasonably perfected that long tunnels without shafts became at all practicable for transportation, although there were several constructed at enormous waste of time and labor, for drainage purposes.

The introduction of efficient drills may be said to date from the first American patent, issued to J. J. Couch, March 27, 1851, for a reciprocating, hollow piston-rod, working in a cylinder, operated by steam, but it had a constant feed and no provision for the rotation of the bit. He took out a second patent November 3, 1852, for some improvements, but in the meantime Stuart Guynn was busy on independent lines in applying the same idea in a practical machine,—also having a constant feed,—but it slumbered from 1851 until the contractor of the Hoosac Tunnel, in Massachusetts, Herman Haupt,* embodied with this hollow piston-rod an automatic feed and rotating device which produced a simple, light and effective drill capable of piercing granite at a rate of one inch per minute and weighing only about 125 pounds. In ordinary shale the speed was doubled. It was estimated that with this tool a progress of twelve feet per twenty-four hours could be made at a cost of $16.33 per lineal foot of single track (15x18), or at about half the price of hand work, and with four times the speed.

To prevent the loss of time in clearing the heading from the debris and gases incidental to blasting—as well as to facilitate the drilling of the holes—a system was devised by the contractor whereby the drills were mounted in series of three or four on columns, which served both as supports and feed pipes for power (steam or compressed air). Thus mounted the drills had a large range in altitude or azimuth, as shown in Fig. 1. The jacks for clamping the stanchions in position and the ball and socket joint at the bottom of frames enabled the bits to be readily changed without removing the gang. The plant also included a low counterpoised derrick

*Died December 14, 1905.

and truck, enabling the gangs of drills to be rolled to the rear of the heading, which was driven at the bottom. Prepared cartridges were placed in the holes, and held by a plug, wired in series, and discharged by a hand battery, simultaneously. A vacuum fan and conduit laid on the floor soon relieved the heading of foul gases, and the drills were rolled forward, set up, coupled and started without awaiting removal of débris. To protect men and machinery a section of heavy timbers laid on the floor was hoisted by a bell-crank lever to an

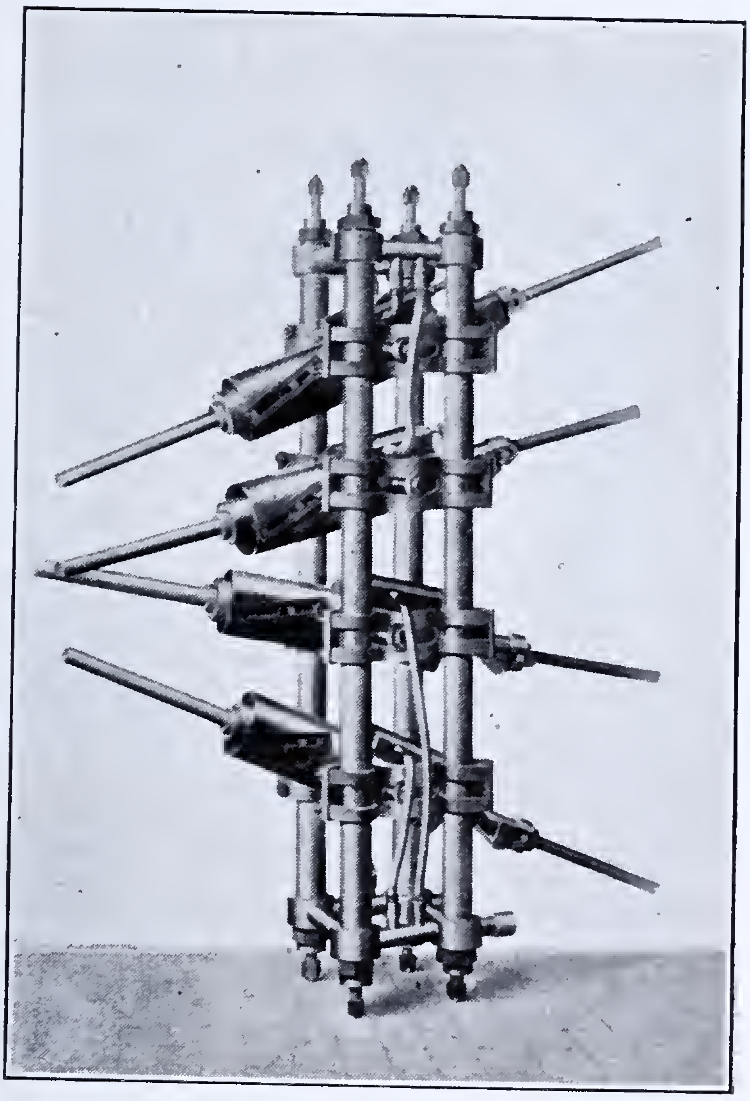

Fig. 1

upright position to serve as a screen during blasting. These several features are clearly shown in Figs 2 to 4, which also illustrate the auxiliary steam plant with tender, when that motor is found to be more expedient.

Modification of this pioneer rock drill were made by Burleigh, DeVolson Wood, and others, to adapt them to the ever varying requirements of the service, and have led to the extensive manufacturing plants of the Ingersoll-Rand, and

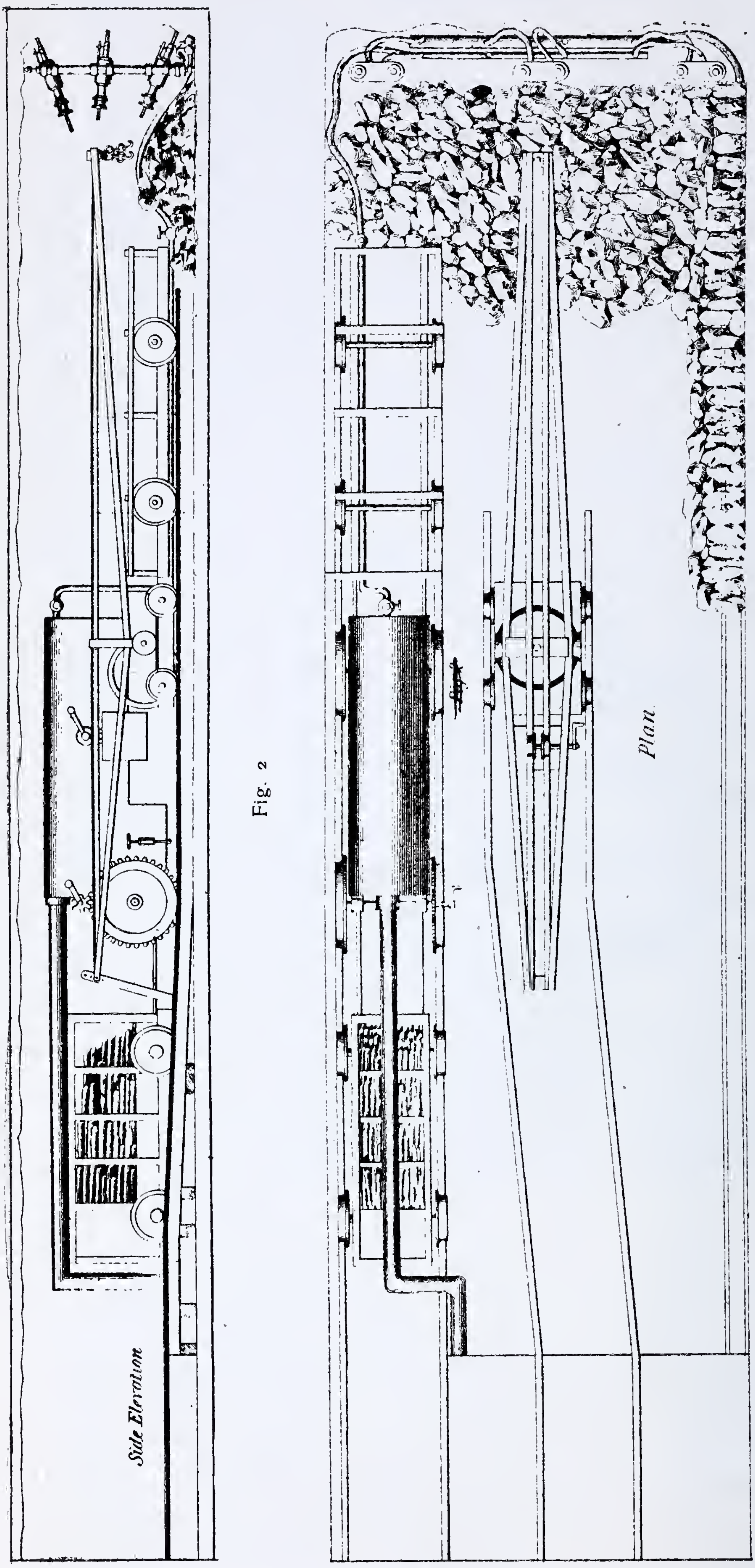

Fig. 2

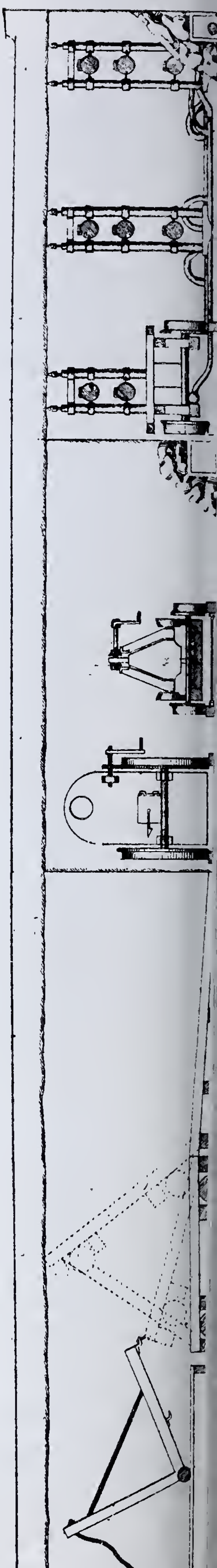

Fig. 3

other companies for supplying complete outfits of tunneling and mining machinery now in common use for all classes of excavations in hard materials.

The contract price for this tunnel was $2,000,000, while the cost was $50 per lineal foot, or for the full length nearly $1,300,000. It was the purpose of the contractor not to use a shaft but to drive from the ends on a rising gradient and ultimately, when the traffic increased sufficiently, to open a parallel tunnel by means of galleries from the first, at frequent intervals, thus greatly reducing the cost, improving the ventilation and avoiding lining. The State, however, saw great political possibilities in this enterprise, and by a change of administration, during the civil war, its control was assumed by the Commonwealth, the dimensions were changed to double track, a large dam built for power, and other radical departures made, which swelled the cost to about $10,000,000, or five times the amount of the original contract. A shaft was sunk 1028 feet in depth, which was of little use in expediting the work and was of doubtful utility. This Hoosac Tunnel of five miles in length, the longest in the United States at the time, was simultaneous with that under Mt. Cenis, where a compressed air plant, operated by water-power, was installed by Mr. Sommellier, the experience from which was a factor in the designing of the plans for the Hoosac, and this in turn, for works of the present day. The close relations of the several long railroad tunnels will become more apparent by a brief chronological statement of their statistics and time of construction.

I. HOOSAC, MASS.

Work was commenced in 1854 and prosecuted by private contractors until the State took possession, September 4, 1862. It was enlarged, and completed July 1, 1876, when it was officially accepted. The total cost of the railroad and tunnel, forty-four miles, was $17,322,019, of which $3,287,835 was interest. The progress was greatly accelerated by the introduction of power drills, 1867, and of nitro-glycerine, in 1870, which was manufactured by Geo. W. Mowbray, in the vicinity of North Adams. This gives an average progress of 5.5 feet per diem.

2. MT. CENIS.* THE ALPS.

The project was first broached by Guisseppe Medail, a Swiss peasant, in 1838, and subsequently, in 1852, M. Colladou suggested driving it by the use of compressed air drills, operated by water-power, but it was not until 1857, after a report by experts, that the Piedmontese Parliament granted a charter and agreed to pay half the estimated cost, which was $7,760,000, but it ultimately paid for the entire work.

The first blast was fired August 18, 1857, and the headings met December 25, 1870. It was opened for use September 17, 1871. It was double-track, driven with bottom heading $9\frac{1}{2}$x$8\frac{1}{2}$ feet. Average rate of progress, 8.00 feet per day. Total length, 42,158 feet, or 8.0 miles. Time, fourteen years in building. Cost, $14,498,352. Machine drills were introduced at the north end in 1861 and at the south end in 1863. The last year the rate was $14\frac{3}{4}'$ a day.

3. SUTRO TUNNEL.

The third long tunnel built was designed to open up the famous Comstock lode, in Nevada, by providing better drainage and greater accessibility to the mines. The section was 12x16 feet and length 20,351 feet, or nearly four miles. Work was begun October 19, 1869, and completed about 1878. There were four shafts designed to be used in construction, three of which were over 1000 feet deep, but two of them were abandoned before reaching grade because of the great influx of water. Progress per day (1875) in heading (10x8) was 10.24 feet.

4. ST. GOTHARD. ALPS (1872-81).

At the St. Gothard tunnel the Sommellier drills were used for a few years but were supplemented by those of McKean & Ferroux, making about 180 blows per minute. These McKean drills were modifications of the system designed for the Hoosac Tunnel and taken to Europe by Blanchard & McKean, agents for the contractor.

The contract for the St. Gothard was awarded to Mr. Louis Favre, August 7, 1872, at an estimated cost of $10,000,000, and

---

*Drinker's Tunneling, p. 266.

was completed in eight years, with a premium of $1000 per diem for every day saved or a similar penalty for each day lost. With the system of rapid firing and removal of débris great progress was made in each heading, and the work was opened in 1880—the first train passed through in 1881.

Its total length is nine and one-quarter miles; time, nine years, five months, and average daily progress, 14.6 feet, notwithstanding great difficulties from water and the caving of the lining. The early location of the approaches was placed high on the mountain slopes instead of the valley bottom, adding

Fig. 5

much to the expense, but this was afterward modified by the use of the spiral tunnel and loops. See Fig. 5.

THE ARLBERG TUNNEL. ALPS (1880-84.)

Through the Austrian Tyrol a tunnel of 6.38 miles was driven between 1880 and 1884 at a much more rapid speed than any of its predecessors, at an estimated cost of $7,000,000. The time consumed was three years, nine months, and the average rate of progress 27.8 feet per diem. Work was conducted very systematically and construction trains were run by time sched-

ules. The headings, which were 7.5 feet high and 9.2 feet wide, were placed at the bottom instead of the top of the tunnel. In cost, therefore, this work was but $1,000,000 per mile, $208 per foot, and in speed of execution three times as fast as Mt. Cenis.

THE SIMPLON. 1893-1905. $12\frac{1}{4}$ MILES LONG.

This tunnel, which connects Brig, in the Valley of the Rhone, with Iselle, on the Diveria, in Italy, is twelve and one-quarter miles in length. The contract was let in September, 1893. The plans contemplated the use of the system proposed for Hoosac of two single-track parallel tubes 16.5 feet wide, 55.7 feet apart, but connected by oblique galleries at frequent intervals. Only one of them was to be completed to full dimensions, while the second was to be used for subsidiary purposes to provide trackage for construction and ventilation, and to await the demands of traffic for its final enlargement. The cost is reported to be $15,500,000 to February 24, 1905, when the headings met, thus opening the shortest route by eighty miles between Paris and Milan, and connecting the Atlantic and the Mediterranean. The large amount of water and high temperature (reaching 118°F.) made this work one of unusual difficulty.

Actual work was begun in 1898, so that the average ratio has been nearly two miles a year, and it is a monument to the enterprise and energy of the countries which have contributed so liberally to the colossal work which at best will save but a few hours in transit between the Italian seaports and the British Isles. (For difficulties from hot springs see Scientific American of March 18 and 25, 1905.)

SUBWAYS.

The feature of the above works is that they have generally been excavated from the ends, without intermediate shafts or slopes. Many more miles of continuous underground ways are now in existence, as in the numerous subways of Continental and American cities, but these have been built largely as open cuts or covered-ways, or with numerous shafts.

SUB-AQUEOUS.

Another important class of structures is the sub-aqueous passages connecting great centers of industries and taking the place of bridges. These involve greater difficulties and risks than are to be found in the previous classes, yet to avoid the transfers, delays and risks of ferries or the obstructions due to bridges, ice and fogs, they are found to be expedient, even at very great cost.

The latest and best practice in works of this kind is illustrated in the extensive system of tubes now completed and under construction by the Pennsylvania Railroad Company, under the direct supervision of Mr. Chas. M. Jacobs, Alfred Noble and others, in and across the rivers surrounding the Island of Manhattan, and connecting its western ramification directly with the greatest seaport of the continent, without break of bulk.

Whilst the tube-system as used underneath the North River at New York has required much ingenuity to adapt it to its purpose, the general idea was first applied in the pioneer work built under the Thames, at London, by M. I. Brunel, in 1825 to 1846. This structure is 1200 feet long, with two passageways 14 feet wide by 16½ feet high, and is now used by the East London Railway.

The influx of mud and water were so great as to cause the invention of a shield to cover the whole face of the excavation, 38 feet wide and 22½ feet high. An attempt was made to introduce the Beach pneumatic system in New York about the year 1863, but it was untimely, and the traffic had not at that time reached such magnificent proportions as to justify the expense, and there was an aversion to being shot through a hole in the ground by the public. Electric motors were not then available. Again, in 1868-69, W. H. Barlow used a modified form of Brunel's shield in building the "Tower" subway under the Thames. This was circular in section, eight feet in outside diameter, and was lined with ribbed cast-iron plates. It was the prototype of the present generally adopted system. In 1889, a pair of tubes, each ten feet in diameter, was laid under the Thames by Mr. Greathead for the South London Railway by means of an improved shield telescoped over the outer end and pressed forward by jacks, as in the Tower subway.

The earliest sub-aqueous aqueduct tunnels in this country were those built at Chicago in 1864-67, two miles long, at a cost of $457,844, and subsequently extended four miles further for a fresh water supply. A second conduit eight feet in diameter and four miles long was added in 1887-1892, and also at Cleveland in 1869-74, when a conduit five feet in diameter and 6,606 feet long was built.

In 1888-1902, the Grand Trunk Railroad built a single-track circular tunnel, lined with cast-iron segments, by the use of shields, under the Detroit River, at Sarnia, through soft clay, sand and gravel 6000 feet in length. To-day similar systems of sub-aqueous tunnels are being rapidly and successfully built under the North and East Rivers.

AQUEDUCTS.

Still another extensive group of tunnels is to be found in the aqueducts for supplying large communities with water. The most conspicuous example of this class is the Croton Aqueduct of thirty-three miles in length and about fourteen feet in diameter, crossing the Harlem River by means of an inverted syphon at a depth of 306 feet below the surface.

DRAINAGE TUNNELS.

Amongst the most interesting works of this class may be mentioned the ancient Desague de Huehuetoca, undertaken by Enrigue Martinez, a Dutch engineer, in 1607, for draining the basin of the City of Mexico. The tunnel was four miles long and the drain thirteen, but before the lining was completed a great flood caused it to cave in. As a reward for his effort the engineer was imprisoned for three years, and when released he was ordered to make an open cut, in which he spent the rest of his life. But the work was continued for 120 years, yet it was not made deep enough to relieve the basin to any great extent. In 1888, another tunnel was built six miles long and 150 square feet in section, supplemented by twenty-seven miles of large canals, this tunnel had twenty-four shafts, varying in depth from 75 to 325 feet and a discharge capacity of 450 cubic feet per second, and furnishes an excellent precedent for the problem now confronting the Isthmian Canal Commission en-

gaged in the regulation of the floods of the Chagres River at Panama, where the success of the enterprise is made to depend upon the diversion of these torrential waters by means of tunnels from seven to ten miles in length through the Cordilleras. But in this case little is known of the geology or stratigraphy, and as to the possibility of any shafts being used.

Before closing these brief remarks it may be found expedient to glance at the attitude of the traffic problem in this city in 1888 as contrasted with present conditions. Then the necessity of additional facilities was urged by the official publications of this Institute, but was opposed by the vested interests handling the interurban traffic, because of the extreme cost of such works and terminals; of the "impossibility of satisfactorily operating the subway;" because "the subway car motor connected with the other lines of the road;" because "it would be unwholesome and unsatisfactory to the public;" because "it would forever preclude the growth of business on the lines of the company and prevent any extensions in the future to meet increased business," and lastly, because "the destruction of the railroad's terminal facilities in Philadelphia would entail a loss* impossible to estimate."

That these objections were untenable is evident from the fact that the "impossible" has vanished, and the underground and elevated roads have come to stay. Councils are now considering the necessity of abolishing all grade crossings and the steam routes are cheerfully asquiescing, while the city and railroad engineers are harmoniously working to relieve the surface from all rapid transit trains, as is best for the interests of all parties.

The Market Street subway contracts for sections 3 and 4, extending from Fifteenth Street west to the Schuylkill River, were let to E. E. Smith on April 1, 1903, and the work, which was begun April 6,, has been vigorously prosecuted so that it is expected to be open for traffic this year (1905). It is designed for four tracks, two of which will carry express trains to connect with the elevated railroad building out Market Street from the east side of the Schuylkill to Delaware County. The four-track bridge across the river is now well under way. The local or

---

*See rapid Transit in Cities, Jan., 1888, Journal of F. I.. Feasibility of Underground Railroads, Dec., 1888, Journal of F. I.

outer tracks will make a loop at the eastern end, passing dow Fifth to Walnut, thence to the River Delaware, to Arch, t Fifth and return to Market. The dimensions, in the clear, are 48 feet 6 inches in width and 14 feet 6 inches in height from to of rails. The roof girders are supported by three rows of stee columns. The side walls are of reinforced concrete, and th work is being carried on without seriously interrupting loca traffic.

Stations are placed at Fifteenth, Nineteenth and Twenty fourth Streets.

Chicago has already constructed some twenty-eight miles o freight and passenger subways at a rate of twenty-one feet pe day from each of the fourteen headings, the material being fir clay (See Scientific American, March 11, 1905) giving the un precedented rate of progress of twelve miles in less than a yea

Boston has built a much-needed underground transit wa which is very popular and which has to some extent relieved th congestion of the surface, and the great work in New Yor goes rapidly on, but it is demonstrated that by the time on system is completed the increase of traffic has reached the lim of its capacity and another is demanded, so that to-day applica tions are being made for new charters under additional street

In view of the record of the past it is reasonable to look fo the construction in the near future of the long-projected tun nels under the Straits of Dover to connect the British Isle with the Continent by a continuous line of rails, and the proje of M. Lobel under Behrings Straits to join Alaska and Siberi and thus furnish an all-rail overland connection between Ne York and St. Petersburg or Paris, or even with Cape Town i Africa, via the Cape to Cairo route.

These are some of the transformations which the engineers o the future may effect in the traffic routes of the world, throug the instrumentality of great tunnels made practical by im proved drilling machinery.

For further details see "Tunneling," by Henry S. Drinker. Johnson Encyclopœdia article Tunnels, by Wm. R. Hatboro. Tunneling by Machi ery, Herman Haupt, 1867.